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Medical diagnoses of heat wave-related hospital admissions in older adults

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ABSTRACT

Heat waves have been associated with adverse human health effects, including higher rates of all-cause and cardiovascular mortality, and these health effects may be exacerbated under continued climate change. However, specific causes of hospitalizations associated with heat waves have not been characterized on a national scale. We systematically estimated the risks of cause-specific hospitalizations during heat waves in a national cohort of 23.7 million Medicare enrollees residing in 1943 U.S. counties during 1999–2010. Heat waves were defined as ≥2 consecutive days exceeding the county's 99th percentile of daily temperatures, and were matched to non-heat wave periods by county and week. We considered 50 outcomes from broad disease groups previously associated with heat wave-related hospitalizations, and estimated cause-specific relative risks (RRs) of hospital admissions on heat wave days. We identified 11 diagnoses with a higher admission risk on heat wave days, with heat stroke and sunstroke having the highest risk (RR = 22.5, [95% CI 14.9–34.2]). Other diseases with elevated risks included fluid and electrolyte disorders [(Hyperosmolality RR = 1.4, [95% CI 1.1–1.3]; Hypoosmolaltiy RR = 1.2, [95% CI 1.1–1.3])] and acute kidney failure (RR = 1.1, [95% CI 1.1–1.2]). These risks tended to be higher under more severe heat wave events. In addition, risks were higher among adults in the oldest (≥85) category (reference: 65–74) for volume depletion and heat exhaustion. Several causes of hospitalization identified are preventable, and public health interventions, including early warning systems and plans targeting risk factors for these illnesses, could reduce adverse effects of heat in the present and under climate change.

1. Introduction

Heat waves have been associated with adverse human health effects, including higher rates of all-cause cardiovascular mortality and emergency hospitalizations, as well as respiratory and renal failure (Bobb et al., 2014a; Bobb et al., 2014b; Thornbrugh et al., 2007; Robine et al., 2008). In the United States, extreme heat caused more deaths than all other extreme weather events combined over the past 15 years (Thornbrugh et al., 2007; Dematte et al., 1998; Robine et al., 2008). With continued climate change, heat waves and extreme weather events are expected to become more frequent, intense, and longer lasting (Bobb et al., 2014a; Meehl & Tebaldi, 2004; Gronlund et al., 2014).

Exposure to extreme heat can affect many organ systems, which may lead to renal failure, neurological impairments, and cardiovascular failure (Leon & Helwig, 2010). Although heat has a range of physiological effects, epidemiological studies of health effects have generally limited their focus to all-cause, respiratory, or cardiovascular disease categories, as well as common diseases like heat stroke and dehydration (Bobb et al., 2014a; Turner et al., 2012). In addition, many studies considered just a single heat wave event, in a particular city or region, rather than prospectively study a large cohort across a broad geographical area (Dematte et al., 1998).

One recent study, which addressed many of the limitations of prior analyses, investigated the full spectrum of diseases that were associated with hospital admissions during extreme heat events in a large population of Medicare enrollees in the United States during 1999–2010 (Bobb et al., 2014a). This study classified approximately 15,000 ICD-9 codes into a more manageable set of 283 clinically meaningful disease groups, and identified 6 disease categories with statistically significant risks of hospital admissions during heat waves (fluid and electrolyte disorders, renal failure, urinary tract infections, septicemia, congestive heart failure (CHF), and other injuries and conditions due to external causes). However, the specific diagnoses that drive the association between these disease groups and heat wave-related hospital admissions have not been characterized. In particular, these 6 disease categories

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comprise 186 distinct diagnosis codes, reflecting heterogeneous biological pathways.

To address this gap, we expanded on this prior study to test the association between heat wave exposure and hospital admissions for each of the medical diagnoses within these disease groups. We further investigated whether the risks increased when the heat wave was more intense (higher temperature) and for a longer duration (additional consecutive days). Finally, we examined whether individuals in older age groups had higher hospitalization risks during heat waves.

2. Methods

We used a linked national database of daily data on hospital admissions and weather for a population of 23.7 million fee-for-service Medicare enrollees (roughly 85% of all Medicare enrollees) residing in 1943 counties in the United States, aged 65 years or older, followed during the period 1999–2010. A complete description of the data has been detailed previously (Bobb et al., 2014a). Briefly, the data comprise parallel time series of daily temperature data from National Centers for Environmental Information (previously National Climatic Data Center), counts of the daily number of cause-specific hospital admissions, defined using the principal discharge diagnosis code [*International Classification of Diseases, Ninth Revision (ICD-9-CM)*], and counts of the daily number of Medicare enrollees at risk of hospitalization (denominator).

We defined a heat wave event as a period of ≥ 2 or ≥ 4 consecutive days with average daily temperatures exceeding the 97th, 98th, or 99th percentile for that county (Bobb et al., 2014a; Anderson & Bell, 2009) (the 2-day, 99th percentile definition was used for the primary analysis). A heat wave day was defined as the second or later day, or fourth or later day (depending on the definition used) during that heat wave period. For each of the 1943 counties, we identified all of the heat wave events during the study period. Heat wave days were matched to non-heat wave days by county and by week: for each heat wave day, we first identified non-heat wave days in that county that were within 3 days of the heat wave day (but in other years) (Bobb et al., 2014a). We then randomly selected one of these candidates as the matched non-heat wave day to achieve 1:1 matching.

To evaluate the cause-specific health risks associated with heat wave exposure, we considered each ICD-9-CM diagnosis code within the 6 broad disease categories (defined using the Clinical Classifications Software (CCS) algorithm of the Agency for Healthcare Research Quality (HCUP CCS, 2015)) previously associated with heat waves (Bobb et al., 2014a). To ensure a sufficient number of events for model fitting, we excluded diagnoses with fewer than 100 total admissions on both heat wave days and non-heat wave days, leaving 50 diagnoses for analysis (Supplemental Table S1). For each diagnosis, we fit log-linear mixed-effect regression models to the matched dataset of heat wave days and non-heat wave days, regressing the daily number of admissions on the heat wave day indicator variable. The model also included an offset for the number of individuals at risk and a county-specific random intercept to account for correlation of daily hospitalizations within a county. We adjusted for possible confounding by temporal trends not addressed through matching by including day of the week and calendar year, both as categorical variables (Bobb et al., 2014a). From the model, we estimated the diagnosis-specific RR of admission comparing heat wave day to a matched non-heat wave day.

3. Results

All 1943 counties had at least one heat wave (under the primary definition), with the median (IQR) number of heat wave days over the study period of 17 (13–20; Table S2). Of the 50 diagnoses considered, 12 had statistically significant RRs under the primary heat wave definition (Fig. 1; Table S3). Of these, 11 had a higher risk of hospitalization during heat wave days as compared to non-heat wave days, and 1 had a lower risk. Seven of the 12 diagnoses with significant risks came from the fluid and electrolytes disorders and the other injuries and conditions due to external causes disease categories. Estimates ranged from an RR of 22.5 (95% CI, 14.9–34.2) for heat stroke and sunstroke (i.e., a 22.5 times higher risk) to an RR of 1.1 (95% CI, 1.0–1.1) for unspecified septicemias.

To evaluate the potential gains of studying individual medical diagnoses, we also compared the diagnosis-specific estimates with the original risk estimates for the broader disease groups (Fig. 1). We found that for all of the disease groups, the individual diagnosis-specific risk estimates were larger (i.e., further from the null) than for the overall category. Notably, as compared to the disease category heat stroke and other external causes, which had a RR of 2.5, the medical diagnoses within that group ranged from 8.0 for heat exhaustion (anhydrotic) to 22.5 for heat stroke and sunstroke.

Among diagnoses where we found significant RRs under the primary heat wave definition, we found higher RRs when the heat wave was more intense (a higher percentile) for most diagnoses (Fig. 2; Table S4); the risks also tended to be higher under the 4-day (versus 2-day) definition, although this trend was less pronounced. Formally, we tested whether the RR under the most severe (≥ 4 days, > 99th percentile) heat wave definition differed from the RR under the least severe (2 days, > 97th percentile), and found a statistically significant difference for six of the diagnoses (Fig. 2).

We further investigated potential effect modification by age, finding evidence of a higher risk of heat wave adverse effects in the oldest (≥ 85) versus youngest (65–74) group for volume depletion and heat exhaustion (Table S5).

4. Discussion

This study provides a detailed characterization of the range of medical diagnoses that occur during heat waves among older adults. We found evidence of a higher rate of hospital admissions for 11 medical diagnoses during heat wave days, including 3 heat-related illnesses, 4 fluid and electrolyte disorders, 2 diagnoses for septicemia, acute kidney failure, and urinary tract infection; we also found 1 diagnosis (CHF) that had a lower risk of hospital admissions during heat waves. Results were robust across alternative definitions of a heat wave that considered different intensities and durations of heat exposure.

Our findings reflect knowledge of the physiological effects of extreme heat, which can cause multiorgan dysfunction (Leon & Helwig, 2010). Not surprising, we found the highest risk for heat stroke, with an RR of 22.5 (95% CI, 14.9–34.2). Heat stroke has been shown to have high emergency department case fatality rates (Hess et al., 2014), when core body temperatures raise and neurological dysfunction may occur (Knochel & Reed, 1994). Mild to moderate heat illness is reversible with prompt treatment; however, its rapid development can be fatal if left untreated. Additionally, hyperthermia associated with heat stroke can lead to the failure of the body's temperature control and regulation system, making the body more susceptible to other bacteria and infection, and possibly correlate with the change in incidence of infections, such as septicemia or urinary tract infection. Another major factor that can cause heat-related illness is dehydration, which can reduce the body's thermoregulation ability through sweating, leading to increases in internal body temperature. Kidney failure has also been associated with several factors that could induce hospital admissions during heat waves, including direct thermal injury and prerenal acute injury correlated with dehydration (Bobb et al., 2014a; Dematte et al., 1998). Lastly, the reasoning behind the potential protective effect of CHF is not solidified. One possible explanation is that large losses of fluid could potentially reduce the risk of volume overload (Bobb et al., 2014a), though this finding could also be due to chance and should be interpreted cautiously. Previous studies have found an increased risk of mortality due to cardiovascular diseases such as CHF (Bobb et al., 2014a; Anderson & Bell, 2009; Basu, 2009), although another meta-analysis did not find a statistically significant association (Turner et al.,

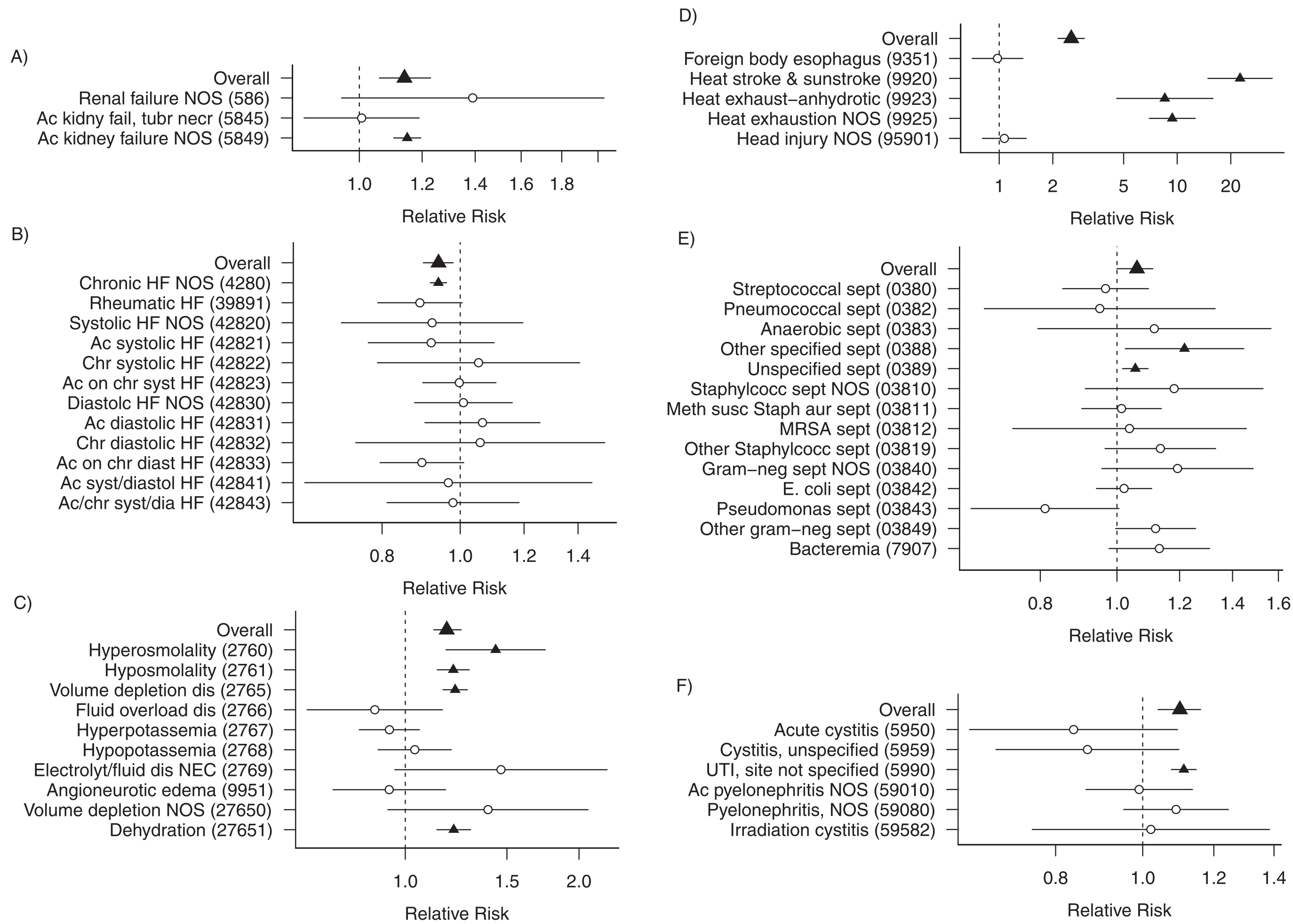

Fig. 1. (A–F): Relative risk estimates (95% confidence intervals) of hospital admissions on a heat wave day as compared to a matched non-heat wave day, for 50 medical diagnosis within 6 disease categories, and for the overall estimate from each category, on average across 1943 U.S. counties during the period 1999–2010. Each diagnosis is labeled with its associated short description, with ICD-9 codes given in parenthesis. A heat wave was defined as a period of at least 2 consecutive days with temperatures exceeding the 99th percentile of the average daily temperature for that county.

A) Acute and unspecified renal failure; B) Congestive heart failure; nonhypertensive; C) Fluid and electrolyte disorders; D) Other injuries and conditions due to external causes; E) Septicemia (except in labor); F) Urinary tract infections.

NOS = not otherwise specified; Ac = acute; tubr = tubular; necr = necrosis; CHF = congestive heart failure; HF = heart failure; NEC = not elsewhere classified; sept = septicemia; UTI = urinary tract infection.

2012).

Because we used the primary discharge diagnosis code to classify diseases, important diseases that were coded as secondary diagnoses could be missed by our analysis. Additionally, some of the diagnosis codes are broader than others—such as “other septicemias”—which may not be as useful compared to more specific diagnoses such as “hypoosmolality”. Another potential limitation is misclassification, which could arise from biased hospital coding and other sources of error. We focused our examination on disease categories that were previously associated with extreme heat in order to minimize the potential for detecting false positives, but as a result, our analysis could neglect important medical diagnoses that do not belong to one of these categories. Third, although we investigated effect modification by age, a systematic investigation of other individual-level factors (e.g., sex, socioeconomic status) or county-level variables (geographic region, air conditioning prevalence) that could modify susceptibility to heat waves would be an important future direction. Finally, studies investigating additional characteristics of the heat waves (e.g., humidity, timing in the season) that may be particularly harmful (Anderson & Bell, 2011), and whether heat wave risks may be modified by air pollution or other meteorological factors would provide further insight into vulnerability to heat-related illness (Buckley et al., 2014; Analitis et al., 2014).

A key strength of this study was our focus on specific medical diagnoses that may be related to heat. We found that some of the risk estimates of the individual diagnoses were substantially greater than the estimates from the corresponding broad disease category. Thus, studies that only consider broad disease categories may be drastically underestimating the risks. For example, we estimated a > 20-fold increase in risk for heat stroke and sunstroke admissions on heat wave days as compared to non-heat wave days, but only a 2.5-fold increase in risk for its broader disease group that also included several other diagnoses that were unrelated to heat exposure. Other strengths include the large, nationally-representative population, the consideration of clinically relevant medical diagnoses (Bobb et al., 2014a), and the evaluation of trend in the risk estimates with increasing severity of the heat wave episode.

Our results have implications for public health and clinical management of disease during heat waves. First, our estimates of the cause-specific risks of hospitalization during heat waves could be combined with projections of future heat wave episodes in order to estimate the health effects of heat waves under climate change. Second, knowledge of the specific medical diagnoses that are most likely to occur during heat waves can enable care providers and health systems to be better equipped for the needs of patients during extreme heat events. Lastly,

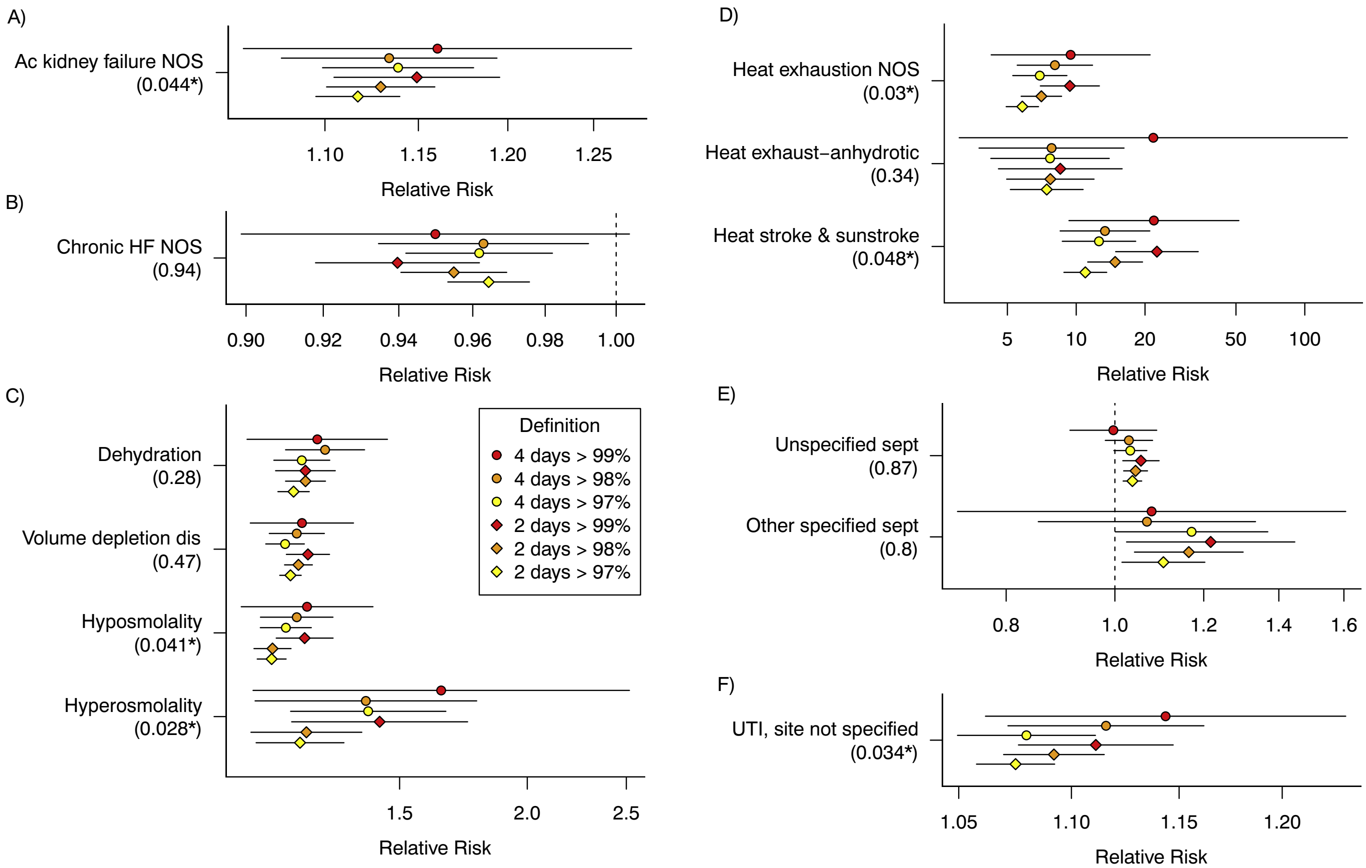

Fig. 2. (A–F): Relative risk estimates (95% confidence intervals) of hospital admissions on a heat wave day as compared to a matched non-heat wave day, across six heat wave definitions capturing increasing duration (number of days) and intensity (temperature percentile), on average across 1943 U.S. counties during the period 1999–2010. P values from the test comparing the relative risk under the most severe (4 day, 99th percentile) heat wave definition to the least severe (2 day, 97th percentile) are shown in parentheses next to the name of the medical diagnosis, with asterisks (*) denoting $P < 0.05$. Results are shown for each of the 12 medical diagnoses having statistically significant risks under the 2 day, 99th percentile definition.

A) Acute and unspecified renal failure; B) Congestive heart failure; nonhypertensive; C) Fluid and electrolyte disorders; D) Other injuries and conditions due to external causes; E) Septicemia (except in labor); F) Urinary tract infections.

NOS = not otherwise specified; Ac = acute; HF = heart failure; NEC = not elsewhere classified; sept = septicemia; UTI = urinary tract infection.

we found that many of the causes of hospital admissions that occur during heat waves are in fact preventable, such as dehydration and heat stroke. For example, eating regular meals and drinking enough water can prevent dehydration during heat waves (Keatinge, 2003). Thus, targeted public health interventions, such as early heat-health warning systems, could be adapted to mitigate heat-related hospitalizations in the present and future climate change.

Conflict of interest disclosures

The authors report no disclosures.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2018.02.001.

References

Analitis, Antonis, et al., 2014. Effects of heat waves on mortality: effect modification and confounding by air pollutants. Epidemiology 25 (1), 15–22.
Anderson, B.G., Bell, M.L., 2009. Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. Epidimiology 20 (2), 205–213.
Anderson, G.B., Bell, M.L., 2011. Heat waves in the United States: mortality risk during heat waves and effect modification by heat wave characteristics in 43 US communities. Environ. Health Perspect. 119 (2), 210–218.
Basu, R., 2009. High ambient temperature and mortality: a review of epidemiologic studies from 2001 to 2008. Environ. Health 8, 40 (PubMed: 19758453).
Bobb, J.F., Obermeyer, Z., Wang, Y., Dominici, F., 2014a. Cause-specific risk of hospital admission related to extreme heat in older adults. J. Am. Med. Assoc. 312 (24), 2659–2667.
Bobb, J.F., Peng, R.D., Bell, M.L., Dominici, F., 2014b. Heat-related mortality and adaptation to heat in the United States. Environ. Health Perspect. 122 (8), 811–816.
Buckley, J.P., Samet, J.M., Richardson, D.B., 2014. Commentary: does air pollution confound studies of temperature? Epidemiology 25 (2), 242–245.
Dematte, J.E., O'Mara, K., Buescher, J., et al., 1998. Near-fatal heat stroke during the 1995 heat wave in Chicago. Ann. Intern. Med. 129 (3), 173–181.
Gronlund, C.J., Zanobetti, A., Schwartz, J.D., Wellenius, G.A., O'Neill, M.S., 2014. Heat, heat waves, and hospital admissions among the elderly in the United States, 1992–2006. Environ. Health Perspect. 122 (11), 1187–1192.
HCUP CCS, June 2015. Healthcare Cost and Utilization Project (HCUP). Agency for Healthcare Research and Quality R, MD. www.hcup-us.ahrq.gov/toolssoftware/ccs/ccs.jsp.

Hess, J.J., Saha, S., Luber, G., 2014. Summertime acute heat illness in U.S. emergency departments from 2006 through 2010: analysis of a nationally representative sample. Environ. Health Perspect. 122 (11), 1209–1215.
Keatinge, W.R., 2003 Sep 6. Death in heat waves. BMJ 327 (7414), 512–513.
Knochel, J., Reed, G., 1994. In: Narrins, R. (Ed.), Maxwell & Kleeman's Clinical Disorders of Fluid and Electrolyte Metabolism, 5th ed. McGraw-Hill, New York.
Leon, L.R., Helwig, B.G., 2010. Heat stroke: role of the systemic inflammatory response. J. Appl. Phys. (Bethesda, Md.: 1985) 109 (6), 1980–1988.
Meehl, G.A., Tebaldi, C., 2004. More intense, more frequent, and longer lasting heat waves in the 21st century. Science (New York, N.Y.) 305 (5686), 994–997.
Robine, J.M., Cheung, S.L., Le Roy, S., et al., 2008. Death toll exceeded 70,000 in Europe during the summer of 2003. C. R. Biol. 331 (2), 171–178.
Thornbrugh, C., Ghertner, A., McNeeley, S., Wilhelmi, O., Harriss, R., 2007. Heat Wave Awareness Project. https://www.isse.ucar.edu/heat/, Accessed date: 15 January 2015.
Turner, L.R., Barnett, A.G., Connell, D., Tong, S., 2012. Ambient temperature and cardiorespiratory morbidity: a systematic review and meta-analysis. Epidimiology 23 (4), 594–606.